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ScienceDirect
Magnetic Resonance Imaging 26 (2008) 109–116
MAGNETIC RESONANCE IMAGING

Single-point imaging with a variable phase encoding interval

Peter Latta[a,b,*], Marco L.H. Gruwel[a], Vyacheslav Volotovskyy[a], Michael H. Weber[c], Boguslaw Tomanek[a]

[a]Institute for Biodiagnostics, National Research Council of Canada, Winnipeg, Manitoba, Canada R3B 1Y6
[b]Institute of Measurement Science, Slovak Academy of Sciences Dúbravská cesta 9, SK-84219 Bratislava, Slovakia
[c]Department of Orthopaedics, University of British Columbia, Vancouver, British Columbia, Canada V5Z 4E3

Received 26 October 2006; revised 4 April 2007; accepted 13 May 2007

Abstract

A modified single-point imaging (SPI) technique using a variable phase encoding interval is proposed. This method is based on the minimization of the phase encoding interval for further signal-to-noise ratio (SNR) optimization. This is particularly beneficial when the maximum gradient amplitude limits an optimal phase encoding interval, and the resulting SNR suffers from T_2-related signal attenuation. Theoretical calculation of the SNR and simulation of the point spread function (PSF) for the different experimental parameters are presented. Experiments using a rubber sample (T_2^*~73 μs) and a tooth (bi-exponential relaxation: $T_{2,1}^*$=111 μs and $T_{2,1}^*$=872 μs) showed a significant increase in SNR (>3 and >2, respectively) when compared with images acquired with conventional SPI.

Keywords: Magnetic resonance imaging; Single-point imaging; Variable time; Phase encoding

1. Introduction

The number of studies of nuclei with very short transverse relaxation time (T_2, T_2^*) is continuously growing [1]. MRI of these short T_2 systems is usually accompanied with difficulties related to extremely short relaxation times of the order of tens to hundreds of microsecond and sometimes, especially in biological systems, the relatively low abundance of the nucleus of interest. Considering the rapid signal decay, the conventional MR spin-warp frequency encoding techniques with extensive and time-consuming gradient switching are not well suited for such tasks. To minimize the necessary time for spatial encoding, the most common strategies for imaging of broad line systems are methods based on chemical shift imaging (CSI) [2], projection reconstruction (PR) [3,4] and single-point imaging (SPI) [5].

The main advantage of CSI is its availability on most medical and experimental spectrometers. Its major drawback, besides the low data acquisition speed, is the fact that gradient switching for spatial encoding is performed between the excitation pulse and the signal sampling. This causes the gradient slew rate to become another limiting factor for the effectiveness of this approach. In order to minimize this limitation, the so-called ultrashort TE CSI (UTE-CSI) has been proposed [6].

The PR method combines the generally higher sensitivity of the frequency-encoded methods with the advantage of short preparation times. However, the reconstruction of the data can be more complicated and often has to deal with difficulties such as nonuniform *k*-space coverage, problems with eddy currents, and sometimes with missing data at the center of *k*-space [4]. In general, PR methods are usually prone to susceptibility artifacts although this is less severe with the short acquisition intervals used in the ultrashort sequences.

Originally, SPI was developed for the imaging of solids [7]; however, it has been used to image broad line resonances in biological systems [8]. This is a pure phase-encoding technique in which a single data point is acquired after a short phase-encoding time T_p in the presence of a gradient (see Fig. 1A). Sometimes SPI is referred to as constant time

* Corresponding author. Institute for Biodiagnostics, National Research Council of Canada, Winnipeg, Manitoba, Canada R3B 1Y6. Tel.: +1 204 984 4544; fax: +1 204 984 7036.
E-mail address: peter.latta@nrc-cnrc.gc.ca (P. Latta).

0730-725X/$ – see front matter.
doi:10.1016/j.mri.2007.05.004

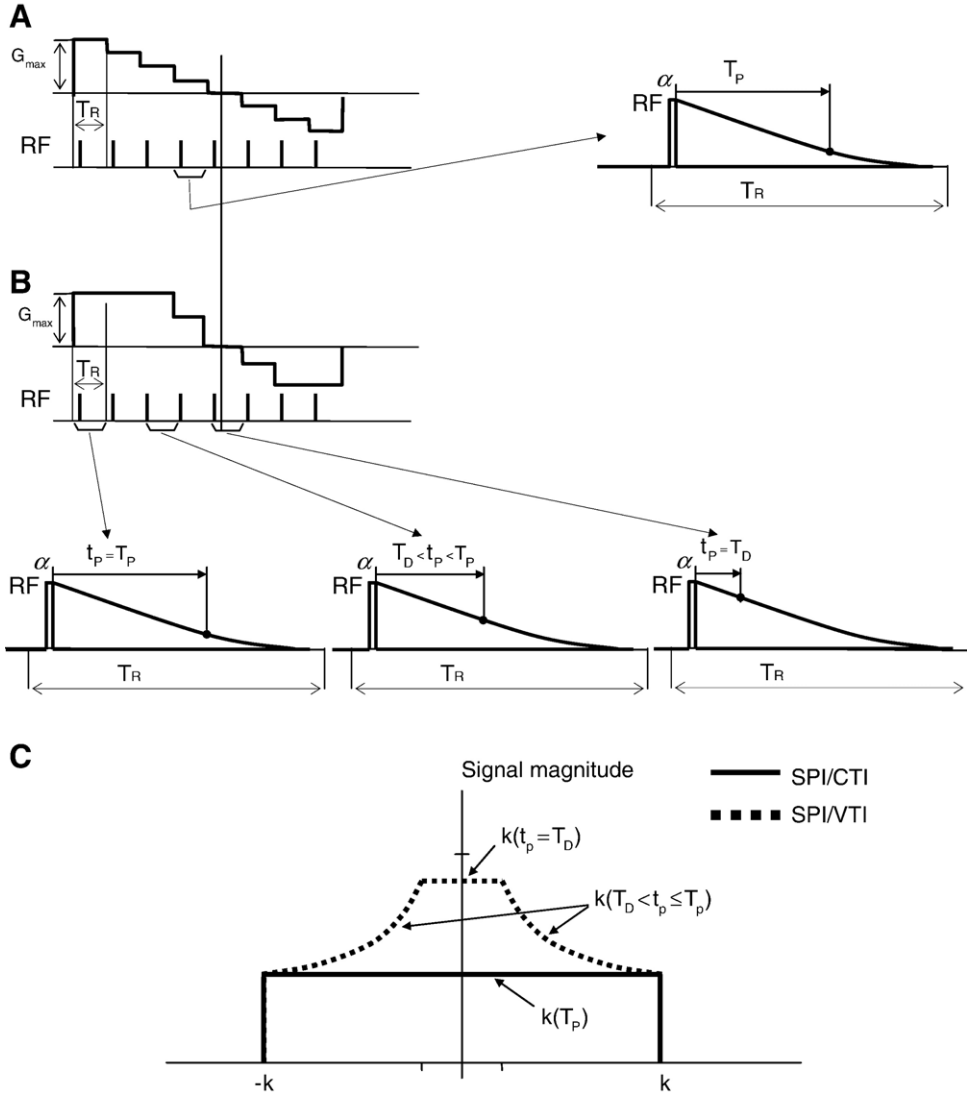

Fig. 1. Pulse sequence diagram showing the difference between SPI/CTI and SPI/VTI (only one phase encoding dimension is shown). (A) In SPI/CTI the gradient amplitude is stepped with a period TR. A phase encoding period T_p between the broad band α-pulse and the acquisition of a single data point is kept constant during the whole experiment. (B) For SPI/VTI, phase encoding is performed by varying phase-encoding gradient amplitudes (when $t_p=T_D$) and times ($T_D<t_p\leq T_p$). (C) Signal magnitudes from a point source for both types of acquisition. While the SPI/CTI signal magnitude is constant (considering the voxel size big enough to neglect the molecular diffusion effect), the amplitude of the SPI/VTI is largest close to the center of *k*-space and dropping down at the *k*-space extremities.

imaging (CTI) because T_p remains constant during the whole experiment. As in SPI only a single data point is acquired for each excitation, it generally poses lower sensitivity per unit of time as compared to its frequency-encoded counterparts. However, it has been shown that for samples with T_2 shorter than the gradient stabilization time, SPI has a higher sensitivity than the conventional spin warp method [9]. It should be noted that the shortest phase-encoding time T_p is not affected by the gradient slew rate and depends only on the available gradient magnitude and the receiver dead time immediately after the RF pulse. In order to improve the efficiency of SPI data acquisition, the so-called single point ramped imaging with T1 enhancement (SPRITE) technique [5] and its various modifications have been proposed [10,11].

Here we propose a modification of SPI, based on the minimization of the phase encoding interval for further signal-to-noise ratio (SNR) optimization. This method can be particularly beneficial when the maximum gradient amplitude limits the selection of an optimal preparation time T_p, resulting in SNR reduction from T_2-related signal attenuation. The method is easy to implement and does not require any additional data reconstruction steps.

2. Theory and method

It has been shown that in SPI, optimal sensitivity (SNR per unit time) is achieved when the phase encoding interval